International Journal of Science, Environment and Technology, Vol. 4, No 3, 2015, 770 – 803

ISSN 2278-3687 (O)
2277-663X (P)

GREEN ALGAE OF A UNIQUE TROPICAL WETLAND, *KUTTANADU,* KERALA, INDIA, IN RELATION TO SOIL REGIONS, SEASONS, AND PADDY GROWTH STAGES

[1]Dhanya Vijayan and [2]Joseph George Ray*

[1]Research Scholar, Environment Science Research Lab, St Berchmans College, Changanacherry, Kerala, India

[2]School of Biosciences, Mahatma Gandhi University, Kottayam, Kerala, India

E-mail: [1]dhanyavinod17@gmail.com , [2]jgray@mgu.ac.in (**Corresponding Author*)

Abstract: Tropical wetland paddy fields are well known for their high algal diversity. Algae of intensively cultivated wetlands are expected to be unique. Since green algae, in general, are cosmopolitan in distribution, ecology of them in specific environment will be interesting to algologist world over. Algae of soils are bio-indicators of pollution and specific soil characteristics. Many algae have significant applications in bioremediation. *Kuttanadu* is a unique tropical wetland and the green algal community of these lands remains unexplored. Therefore, the same in relation to different soil-regions, seasons, and crop-growth-stages are identified. High green algal diversity of 87 species, with Zygnemales as the dominants (33%) is observed in the fields. Highest values for all the ecological parameters analyzed were found in the Lower *Kuttanadu* soil region, during *Virippu* season, at panicle stage of the crop whereas the lowest values for most of the parameters were observed in *Kayal* soils during *Puncha* season at the seedling stage. Overall analysis of algal floral characteristics in relation to those environmental variations in these paddy fields revealed that apart from the specific soil and climatic factors, crop growth stages play significant contribution to algal diversity, species richness and their evenness in wet soils, especially paddy fields.

Keywords: Green-Algae, Paddy-Growth-Stages, Seasons, Soil-regions, Wetland.

Introduction

Rice (*Oryza sativa L)*, the staple diet of about 50% of the world population (Kogel-Knabner et al. 2010) is cultivated over 150 million hectares belonging to 114 countries in the world (Gayatri and Raveendran 2009). Seventy five percent of paddy fields are wetlands, where rice grows under flooded conditions (Roger et al. 1993). Flooded paddy soils represent unique wetland soil habitats (Sahrawat 2008). Such submerged anaerobic soil environments (Kumar and Sahu 2012) with varying amounts of light, water, temperature and nutrients are variable in accordance with soil regions, seasons and growth stages of the crop. Paddy fields in general are considered precious environments for high algal diversity (Inbushi and Acquaye 2004). Since they are highly disturbed soil environments (Prakonkep et al. 2008; Kogel-

*Received April 30, 2015 * Published June 2, 2015 * www.ijset.net*

Knabner et al. 2010; Bahaar and Bhat 2011) subjected to intensive physico-chemical operations, algae in such environments can be unique. Algal species of such soils may be indicators of specific wetland soil characteristics.

Algae are the distinct autotrophic micro community of all wet soils. Algae carryout 90% of the photosynthetic activities on this earth (Guru 2013). They contribute to approximately half of the total global primary production (Graham and Wilcox 2000). Algae, the fastest growing plants in the world (Demirbas and Deemirbas 2011) are critical to the functioning of global ecosystems (Shayler and Siver 2006). Majority of algal species are cosmopolitan in distribution (Patova and Dorokhova 2008) and the ecology of them in any specific environment will be interesting to algologist world over. Many algae have significant role in bioremediation (Novakovskaya and Patova 2008). Green algae are biochemically similar to higher plants with quick generation time (Metting 1981) and have applications in the biological assay for crop response to both fertilizers and pesticides. Green algae serve as antagonists against soil inhabiting plant pathogens (Lartey 2006). They have significant role in oxygenation of the surroundings, which is significant to root growth. As producers of very nutritious and palatable biomass they are essential to the existence of various delicate consumer organisms contributing to sustainable management of soil fertility. Therefore, identifying all of them from all kinds of ecosystems in relation to their surroundings is a significant task of biologists.

Kuttanadu is a unique flooded paddy land in the South India, which belongs to the *Vembanadu* Ramsar site. Algal community of this wetland paddy soils remains quite unexplored. Different regions of cultivation in the *Kuttanadu* in the monsoon and non-monsoon seasons create distinct local wetland environment situation suitable for ecological inventory of green algae. Regional variations in water quality and differences in crop growth stages add further specificities to local environmental conditions. All these contribute to uniqueness of algal community of *Kuttanadu*. Therefore, an intensive study of specific algal communities of the *Kuttanadu* wetland soils became highly relevant. The main objective of the investigation was to understand the status of diversity and dynamics of green algal populations in terms their relative abundance and correlation to soil conditions such as soil pH, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg) of the three distinct soil regions (Upper-*Kuttanadu*, Lower-*Kuttanadu* and *Kayal*-lands) in two

different crop-seasons (the *Puncha* and *Viruppu*) at the two different growth-stages (the seedling and panicle stage) of paddy.

Materials and Methods

Study Area

Kuttanad (9^0 17'- 9^0 40' N and 76^0 19'- 6^0 33' E) is the deltaic formation of five rivers flowing eastwards from the Western Ghats of the South India. It is the well known 'Rice bowl' or granary of Kerala and a unique wetland spread over 53,639 hectares (Sudhikumar et al. 2005)**.** It is a warm and humid region spread over Alappuzha, Kottayam and Ernakulam Districts of Kerala, South India. The seasonal fluctuation in temperature of the region is 21-38º C. The average rainfall received is around 300cm, of which, 83% is received during monsoon period from June to October (Shari and Chithra 2005). The peculiarity of *Kuttanadu* is that it occurs below the mean sea level and remains water-logged throughout the year except during paddy crop seasons when water is pumped out from the fields. Agricultural practices and cropping techniques are also unique. Major portion of the land is cultivated twice a year; '*Puncha*' the main crop is sown in November or December and harvested by the end of March (non-monsoon crop), '*Virippu*' the additional crop is sown in May to the end of June and harvested in September or October (monsoon crop).

The average amount of chemical fertilizers (N+P+K) of marginal, small, medium and large farmers in *Kuttanadu* lands is estimated to be 162.1, 184.3, 192.9 and 176.3 kilograms per acre respectively (Thomas 2002). The application of chemical fertilizers is done two to three times in a single crop season; on an average, farmers apply 178.9 kg of chemical fertilizer per acre. Use of lime to (average of 122 kilograms per acre) neutralize the high level of acidity emerged in the soil at times, is also common in many parts of these wetlands.

Three Soil Regions of Kuttanadu: Based on elevation, geographical features and agronomic characteristics, the land is divided into three soil-regions, Upper *Kuttanadu*, Lower *Kuttanadu* and *Kayal* lands. The Upper *Kuttanadu* is situated along Rivers that form the eastern and southern periphery of *Kuttanadu*, lying 0-2m below mean sea level. The Lower Kuttanadu areas, situated between Upper *Kuttanadu* and *Kayal* lands are situated at an average of 2 m below mean sea level. The *Kayal* lands represent the reclaimed *Vembanad* Lake beds for agricultural purpose and the elevation ranges from 2 to 3m below the mean sea level. On the basis of geological features and biochemical characteristics, soils of *Kuttanadu*

are grouped into three categories such as *Karappadom*, *Kari* and *Kayal* soils (Pillai et al 1983).

Karappadom soils spreads over a large part in the Upper *Kuttanadu* covering an area of about 42,505 hectares. These are mainly river-borne alluvial soils located more towards the interior regions away from *Vembanadu* Lake and exhibit lesser salinity than that of the *Kayal* and *Kari* soils. The colour of the soil of Lower *Kuttanadu* varies from dark grey to deep brown or black. The surface soils are generally clay loams and characterized by high acidity and a fair amount of decomposing organic matter and nitrogen. These are generally deficient in available plant nutrients particularly so in phosphorus.

Kari soils are deep black in colour due to relatively higher proportion of organic matter, characterized by acidity and salinity. Such soil is seen mostly in lower *Kuttanadu* regions and rarely in the upper *Kuttanadu* zones. They are peat soils found in large isolation patches in Alleppey and Kottayam districts covering an area of about 6,075 hectares. They exhibit characteristics of submerged non-silted-up soils, and are representing the ancient mangrove forest area (Nair 2013). Soil of the region is characterized by heavy texture, poor aeration, bad drainage and low amount of available plant nutrients. Presence of sulphur bacterial cycle is known in *Kari* soils (Mathew et al. 2001). Free sulphuric acid is formed in these soils by the oxidation of sulphur compounds from the ancient vegetation that remains in the soil. Large amounts of woody matter of burned nature at various stages of decomposition are found buried at varying depths in this soil region. This zone is usually affected by saline intrusion with consequent accumulation of soluble salts.

Kayal soils are the reclaimed shallow beds of *Vembanadu* Lake, lying in the districts of Kottayam and Alleppey. They occupy an area of about 8100 hectares. They are deep and poorly drained soils with a dark brown colour. The texture varies from silt-loam to silt-clay-loam. They are slightly acidic to neutral in reaction, but tend to be saline due to the incursion of sea water during tidal flows. This soil contains low organic matter and is poor in total and available plant nutrients, but is fairly rich in calcium.

Presence of endemic flora and fauna is an important character of this wetland (Freyfogle 2007). The large water expense and the unique intermixing of the same with sea water make *Kuttanadu* an interface ecotone between land and saline water with high biodiversity. It is believed that once up on a time, the brackish water environments of *Kuttanadu* promoted a rich diversity of mangroves and provided ideal habitats for diverse flora and fauna.

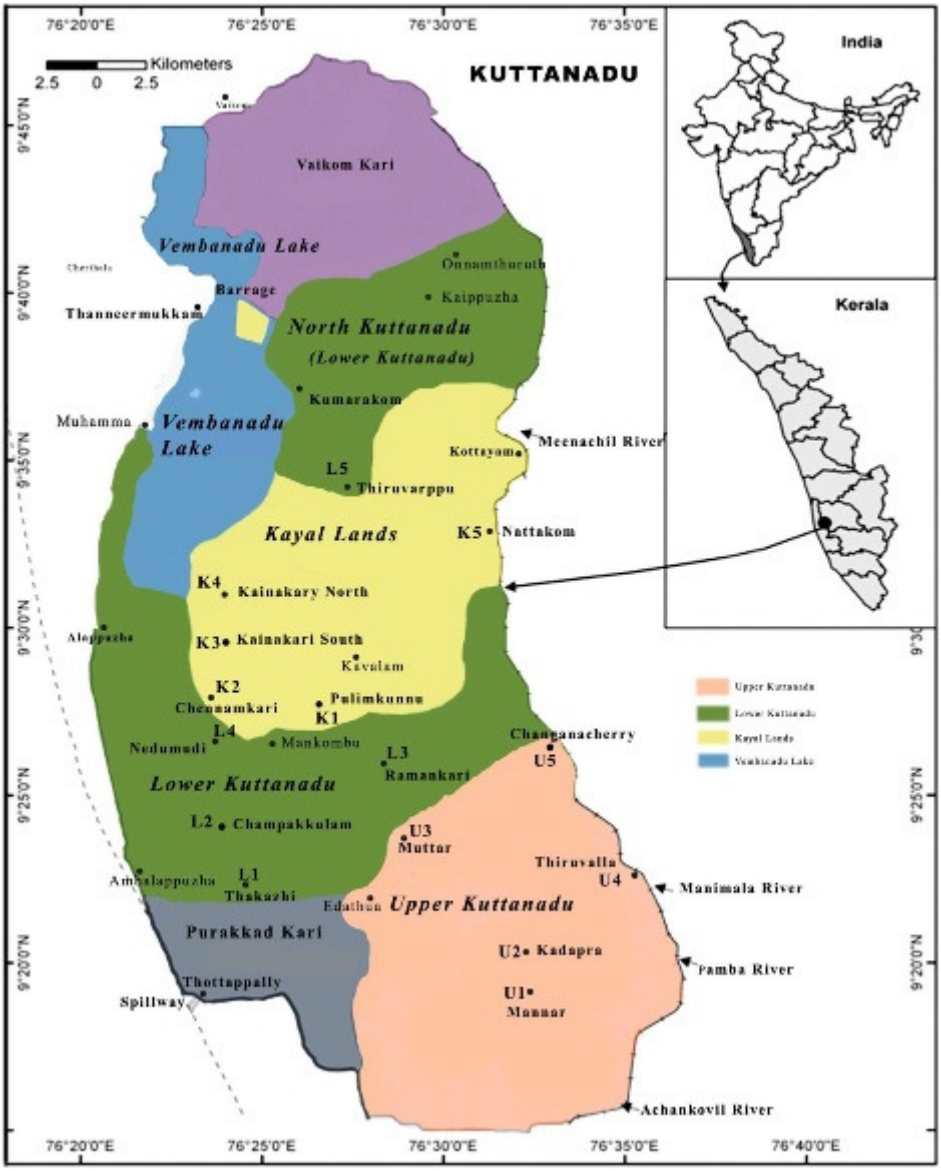

Figure 1: Map of *Kuttanadu*, Kerala, India showing the sampling sites

Sampling *sites:* Altogether, there were15 study sites (fig 1) distributed in the three different soil regions of *Kuttanadu* namely the Upper *Kuttanadu,* the Lower *Kuttanadu* and the *Kayal* lands. The Upper *Kuttanadu* soil samples were collected from five different sites (U1 to U5) such as *Mannar, Kadapra,* and *Muttar* of *Alappuzha district, Thiruvalla* of Pathanamthitta district and *Changanacherry* of Kottayam district. The Lower *Kuttanadu* soil samples were collected from five different sites (L1 to L5) such as *Thakazhi, Chambakulam, Ramankari* and *Nedumudi* of *Alappuzha* district and *Thiruvarppu* of Kottayam district. *Kayal* land soil samples were collected from five different sites (K1 to K5) such as *Pulimkunnu,*

Chennankari, Kainakari south and *Kainakari north* of *Alappuzha* district and *Nattakom* of Kottayam district.

Soil sampling Procedure: Soil sampling was carried out by standard methods. Samples were systematically collected from all the three soil regions in two seasons; in every season samples of two growth stages were collected. At each site two broad specific paddy fields located at 1-2 km intervals were selected for sampling. In each specific field, several plots (5-10) of about $10m^2$ areas were identified for sampling. Several soil samples (5-10 from a plot) from the upper 1-5 cm soil layer from all these plots were collected and put together in a sterile cotton bag using aseptic implements. Repetitive samples put in each cotton bag from different field plots of a single paddy field on air drying were mixed thoroughly to a composite sample. There were five sites in a soil region and there were 10 different composite samples for each growth stage representing a season from the region. Since there were five sites, two sampling fields for each site, two crop seasons (the *Puncha* - summer crop of December 2009 to March 2010; the *Virippu* - the additional crop of June 2010 to October 2010) to sample and two crop-growth stages (seedling stage and panicle stage) at each season to sample, altogether, 40 composite soil samples (5 x 2 x 2 x 2) were collected from each soil region. Altogether, there were 120 composite soil samples (3 x 40) representing the three soil regions of *Kuttanad* - the Upper, the Lower and the *Kayal* zones for the soil study. Specific soil samples for algal studies also were collected simultaneously from all the sites in the same way.

Physico-chemical analyses of soil samples: Physico chemical analyses were completed within two weeks after the collection. Determination of pH (1water : 2.5 soil), was done using pH meter (Systronics 324) organic carbon (Walkley and Black 1934) total nitrogen (Microkjeldahl method), and available Phosphorus (Bray and Kurtz 1945)**,** Potassium (Flame photometric method), Calcium and Magnesium (Atomic Absorption Spectrometry, Perkin Elmer A Analyst-400) were done by standard analytical procedures (Jackson 1973).

Soil algal studies: Filamentous algal specimens collected directly from the field were brought to the lab, carefully washed and preserved in 4% formaldehyde solution. Microscopic studies were carried out including micrometric measurement for each of the specimen. Isolation and culture of soil algae were carried out as per standard procedures (Mansour and Shaaban 2010; Zancan et al. 2006); 10 gm of each of the air dried soil samples were dissolved in 100ml and serially diluted; 1gm/1ml is transferred to the conical flask containing

sterilized Modified Bold's Basal medium (MBBM) prepared (Pena-Castro et al. 2004). Solid medium in Petri plates and liquid medium in 250 ml conical flask were incubated at 25 ± 2º C under continuous light intensity of 4000 lux 24-28 days prior to counting and identification processes.

Characterization of the Biodiversity: Microscopic study of field samples and mono-algal culture of algae from different regions of *Kuttanadu*, in different seasons at different paddy growth stages were used to identify the total biodiversity of green algae. Photographs of green algae were taken using Olympus digital Camera attached to the microscope. Systematic keys (Iyangar and Deshikachary 1981; Philipose 1967; Prescott 1951 Pham et al. 2011) were used in the identification of species. All the green algae were identified up to species level.

Environment relationships and population dynamics of algae: Correlation of algae to environmental factors such as region, season, and physiochemical soil parameters are described. Relative abundance of species in the community is determined by the formula Y/X x **100,** where 'X' is the total number of samples collected and 'Y' is the number of samples from which algae was isolated (Dey et al. 2010). Diversity index (Shannon Wiener Index) and Species richness of all species of green algae in different season were worked out (Shannon and Weaver 1949) using the formula:

$$\mathbf{H_s = -\sum_{i=1}^{s} (P_i)(\ln P_i)}$$

where, H_s is diversity in a sample of 's' species or kinds, 'S' is the number of species, P_i is the relative abundance of ith species or kinds, N is the total number of individuals, ni is the number of individuals of ith species, 'ln' is log base 2. Species richness was calculated with the following formula :

$$\mathbf{D = \frac{n}{\sqrt{N}}}$$

(Whittaker 1977), where 'n' is the number of different species in the sample and N is the total number of individual organism in the sample. Species Evenness was calculated by the following formula **E= H / ln (S)**. All the data of species richness and diversity index were statistically analyzed by PAST package.

RESULTS

Altogether 87 species of green algae belonging to 43 genera have been reported from the entire *Kuttanadu* paddy fields during the one year study period (2009-10). Among 87 species

of green algae identified, 27 species were seen only in culture, 8 species were seen both in culture and fresh soil samples, 52 species were observed in fresh soil samples only. Cosmarium genus dominated the algal flora of *Kuttanadu* with 8 species followed by Closterium (6 species), Scenedesmus (5 species) and Trachelomonas (5 species). All the species observed are shown in Table -1, as per the classification system of Guiry and Guiry (2012).

Table: 1 Variation of soil algae of *Kuttanadu* paddy fields in different regions, seasons and crop stages

No	**Chloropyceae** species	R1				R2				R3			
		S1		S2		S1		S2		S1		S2	
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
Order : Volvoccales													
1	*Pandorina morum* (Mull.) Bory*	+	+	+	-	-	-	-	-	-	-	-	-
2	*Chlamydomonas reinhardtii* Dangeard*	+	+	+	+	-	-	-	-	-	-	-	-
3	*Chlamydomonas debaryana* Goroschankin*	+	+	+	+	+	-	-	-	-	-	-	-
4	*Chlamydomonas intermedia Chodat**	+	+	+	-	-	-	-	-	-	-	-	-
Order : Chlorococcales													
5	*Chlorococcum infusionum**	+	+	+	+	-	-	-	-	+	+	+	+
6	*Chlorococcum humicola* (Nageli)Rabenhorst***	+	+	+	+	+	-	+	+	+	-	+	-
7	*Chlorococcum minutum* Starr***	+	-	+	+	+	-	+	+	+	-	+	-
8	*Chlorococcum macrostigmatum* Starr***	+	+	-	+	+	+	+	+	+	+	-	-
9	*Myrmecia bisecta* Reisigl*	-	-	-	-	+	+	+	+	-	-	-	-
10	*Dictyochloropsis reticulatum (TschermakWoess)Tschermak Woess**	+	-	-	-	+	+	-	-	+	+	+	+
11	*Dictyochloropsis splendida* Geitler var.splendida*	+	-	-	-	+	+	-	-	+	+	+	+
Order : Sphaeropleales													
12	*Dictyococcus varians* Gerneck*	+	-	+	+	-	-	-	-	-	-	-	-
13	*Gleocystis gigas* (Kutzing) Lagerheim*	+	-	-	-	-	-	-	-	+	+	+	+
14	*Characium accuminatum*	+	+	+	-	-	-	-	-	-	-	-	-

	A.Braun ex Kuetzing*												
15	*Pediastrum duplex* Meyen reticulatum**	-	-	-	-	-	-	+	+	-	-	-	+
16	*Pediastrum tetras***Her(Ralfs)	-	-	-	-	-	-	-	+	-	-	+	-
17	*Scenedesmus alternans* Reinsch***	+	+	-	+	+	+	+	+	+	+	+	+
18	*Scenedesmus arcuatus* Lemmermann***	+	+	+	+	+	+	+	+	+	+	-	+
19	*Scenedesmus brasiliensis* Bohlin**	+	-	+	+	+	+	+	+	+	-	+	-
20	*Scenedesmus quadricauda Var*.Quadrispina (Chodat) G.M .Smith***	+	-	+	+	+	+	+	+	-	-	+	+
21	*Scenedesmus bijuga* (Turpin) Kutzing***	+	+	+	+	+	+	+	+	+	+	-	-
22	*Coelastrum reticulatum* (Dangeard) Senn.**	-	-	-	-	-	+	+	+	-	-	-	-
23	*Coelastrum astroidem* De Notaris**	-	-	-	-	-	-	+	+	-	-	-	-
24	*Coelastrum microsoprum* Nageli **	-	+	-	-	-	-	+	+	-	-	+	-
25	*Coelastrella terrestres* (Reisigl) Hegewald &Hanagata*	+	+	+	+	-	+	+	-	-	-	-	-
26	*Coelastrella vacuolata* (Shihira et krauss) Hegewald et Hanagata*	+	+	+	+	-	-	-	-	-	-	-	-
27	*Bracteacoccus minor* (Chodat) Petrova*	-	-	-	-	+	+	+	+	-	-	+	-
28	*Selenastrum gracile* Reinsch*	-	-	-	-	+	+	-	-	-	-	-	-
29	*Ankisrodesmus densus* Korshikov*	-	-	+	-	-	-	-	-	-	-	-	-
30	*Ankistrodesmus falcatus* (Corda) Ralfs*	+	+	-	-	-	-	-	-	-	-	-	-
31	*Monoraphidium griffithii (Berkeley) Komarkova Legnerova**	+	+	-	-	-	-	-	-	-	-	-	-
Order :Ulothricales													
32	*Ulothrix moniliformis* Kutzing**	-	-	-	-	+	+	-	-	-	-	-	-
Order : Odegoniales													
33	*Oedogonium sp***	+	+	+	+	-	-	-	-	-	-	-	-
34	*Oedogonium sp***	+	+	-	-	-	-	-	-	-	-	-	-
Order :Microsporales													
35	*Microspora tumidula* Hazen*	+	+	-	-	-	-	-	-	-	-	-	-

Order : Chaetophorales													
36	*Chaetophora attenuate Hazen* **	+	+	-	-	-	-	+	+	-	-	-	-
37	*Chaetophora elegans* (Roth) C.A.Agardh**	+	+	-	-	-	-	+	+	-	-	-	-
Order : Chladophorales													
38	*Cladophora glomerata* (L.) Kutzing**	+	+	-	-	-	-	+	+	+	-	-	-
Order : Chlorellales													
39	*Chlorella minutissima* Fott et Novakova*	+	-	+	+	+	+	+	+	+	-	-	+
40	*Chlorella vulgaris* Beyerinck*	-	-	-	-	-	-	-	+	+	+	+	+
41	*Chlorella minuta* (Nageli)Oltmanns*	-	-	-	-	-	-	-	-	+	+	+	+
42	*Keratococcus bicaudatus* (A.Braun ex.Rabenhorst) J.B Petersen*	-	-	+	+	-	-	-	-	-	-	-	-
Order : Oocystales													
43	*Oocystis solitaria* Wittrock*	-	+	+	-	-	-	-	-	-	-	-	-
44	*Oocystis ellipticaWest**	-	+	-	-	-	-	-	-	-	-	-	-
45	*Sideroceles ornata* (Fott) Fott*	-	+	-	-	-	-	-	-	-	-	-	-
Order : Prasioles													
46	*Stichococcus bacillaris* Nageli*	-	-	-	-	+	+	+	+	-	-	-	-
47	*Hormdium fluitans* (Gay) Heering**	-	-	-	-	-	-	+	+	-	-	-	-
Order : Klebsormidiales													
48	*Klebsormidium flaccidum* (Kutzing) S.Mattox et Black well**	-	-	-	-	+	+	+	+	-	-	-	-
Order : Zygnemales													
49	*Mesotaenium macrococcum* (Kutzing) Royet Bisset***	-	-	-	-	-	-	+	+	-	-	+	+
50	*Cylindrocystis crassa* De Bary*	+	+	+	+	-	-	-	-	-	-	-	-
51	*Closterium jenneri* Ralfs var.jenneri**	-	-	-	-	-	-	+	+	-	-	+	+
52	*Closterium navicula* (Brebisson) Lutkemuller**	-	-	-	-	-	-	-	+	-	-	+	+
53	*Closterium pusillum* Hantzsch**	-	-	-	-	-	-	+	+	-	-	+	+
54	*Closterium incurvum* Brebisson**	-	-	-	-	-	-	+	+	+	-	+	+
55	*Closterium kuetzingii*	-	-	-	-	-	-	+	+	-	-	-	+

	Berbisson var.kuetzingii**												
56	*Closterium closteroides* (Ralfs) Lousis et Peeters var.intermedium Roy et Bisset**	-	-	-	-	-	-	+	+	-	-	+	+
57	*Pleurotaenium trabecula* (Ehrenb.) Nageli**	-	-	-	-	-	-	-	+	-	-	-	+
58	*Euastrum ceylanicum*(W.et GS West) Krieger**	-	-	-	-	-	-	-	+	-	-	-	+
59	*Euastrum spinulosum* Nordstedt**	+	+	+	+	-	-	-	-	-	-	-	-
60	*Micrasterias foliacea* Bailey ex Ralfs**	+	+	+	+	-	-	-	-	-	-	-	-
61	*Cosmarium blyttii* Wille**	-	-	-	-	-	-	+	+	-	-	+	+
62	*Cosmarium quadratulum* (Breb) Arch.**	-	-	-	-	-	-	+	+	-	-	+	+
63	*Cosmarium auriculatumReinsch***	-	-	-	-	-	-	+	+	-	-	+	+
64	*Cosmarium quadrum*.Lund**	-	-	-	-	-	-	+	+	-	-	+	+
65	*Cosmarium speciosum* Nordst.**	-	-	-	-	-	-	-	+	-	-	+	+
66	*Cosmarium awadhense* (Prasad and Mehrotra)**	-	-	-	-	-	-	-	-	-	-	+	+
67	*Cosmarium granatum* Breb ex Ralfs**	-	-	-	-	-	-	+	+	-	-	-	-
68	*Cosmarium angulosum* Berb**	-	-	-	-	-	-	+	+	-	-	+	+
69	*Staurastrum gracile* Ralfs var.coronulatum Boldt forma**	-	-	-	-	-	-	-	+	+	+	-	+
70	*Staurastrum apiculatum* Brebisson**	-	-	-	-	-	-	-	+	-	-	+	+
71	*Sphaerozosma vertebratum* Breb ex Ralfs**	+	+	+	+	-	-	-	-	-	-	-	-
72	*Actinotaenium turgidum* (Brebisson) Teiling**	-	-	-	-	-	-	-	+	-	-	+	+
73	*Mougetia scalaris* Hassall**	-	-	-	+	-	-	+	+	-	-	-	-
74	*Zygnema pectinatum* (Vaucher) Agardh**	-	-	-	-	-	-	+	+	-	+	+	+
75	*Spirogyra fluviatilis* Hilse**	-	-	-	+	-	-	+	+	-	+	+	+
76	*Spirogyra decimina* (Muell) Kuetz **	-	-	-	+	-	-	+	+	-	+	+	+
77	*Spirogyra longata* (Vaucher)Kutzing**	-	-	-	-	-	-	+	+	-	+	+	+
Order : Euglenales													
78	*Euglena gracilis* Klebs**	+	-	-	+	-	+	+	+	-	+	+	+

79	*Euglena tripteris* (Dujardin)Klebs**	+	-	-	+	-	+	+	+	-	+	+	+
80	*Trachelomonas hispida*(Perty)Stein var.hispida**	+	-	-	+	-	+	+	+	-	+	+	+
81	*Trachelomonas superba* Svirenko emend.Deflandre**	-	-	-	+	-	+	+	+	-	+	+	+
82	*Trachelomonas rugulosa Stein***	+	-	-	+	-	+	-	+	-	+	+	+
83	*Trachelomonas armata Lemmermann***	+	-	-	+	+	+	-	+	-	-	+	+
84	*Trachelomonas dubia* (Svirenko) Deflandre**	-	-	-	-	-	-	+	+	+	+	+	+
85	*Phacus longicauda* (Ehrenberg) Dujardin**	+	-	+	+	-	+	+	+	-	-	+	+
86	*Phacus curvicauda* Swirenko.**	+	-	+	+	-	+	+	+	-	-	-	-
87	*Phacus acuminatus* Strokes var. variabilis (Lemmermann)**	-	-	+	+	-	+	+	-	-	-	+	+
Total number of species		**40**	**29**	**27**	**33**	**19**	**25**	**48**	**56**	**18**	**21**	**42**	**43**

***Species seen only in culture **Species seen only in soil sample ***Species seen both in soil and culture**

The fourteen orders observed in this wetlands were Volvocales (2 genera, 4 species), Chlorococcales (3 genera, 7 species), (1 genus, 1 species), Sphaeropleales (11 genera, 20 species), Ulothricales (1 genus, 1 species), Oedogoniales (1 genus, 2 species), Microsporales (1 genus, I species), Chaetophorales (1 genus, 2 species), Chladophorales (1 genus, 1 species), Chlorellales (2 genera and 4 species), Oocystales (2 genera, 3 species), Prasioles (2 genera, 2 species), Klebsormidiales (1genus and 1 species), Zygnemales (14 genera, 29 species), and Euglenales (3 genera, 10 species). Zygnemales was the largest order with about 33% of the total green algal species identified. The percentage distribution of different orders of green algal members observed in the area are presented in Fig: 2

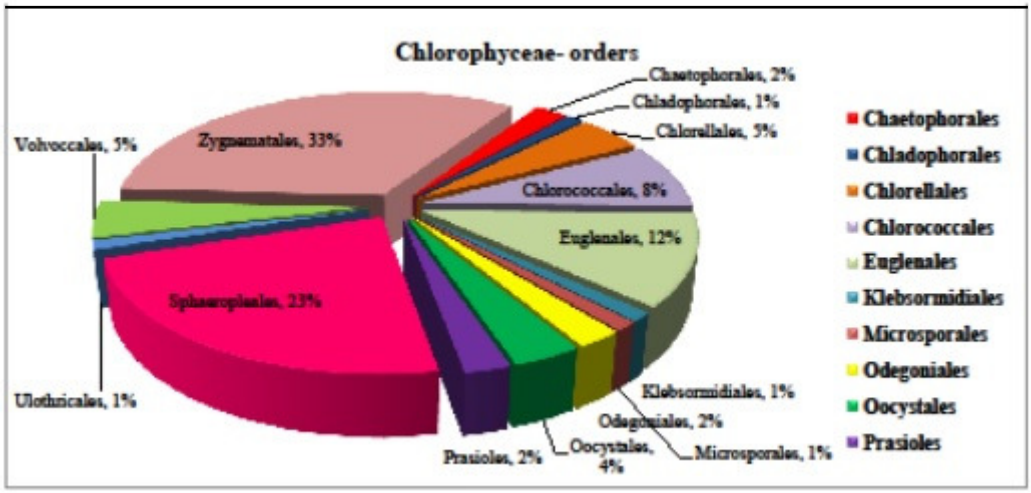

Figure 2: Diversity of different groups of Chlorophyceae in *Kuttanadu* paddy fields

Table: 2 Relative abundance (%) of occurrence of soil algae in *Kuttanadu* paddy fields in different regions, seasons and crop stages

No	Chloropyceae species	R1				R2				R3				Abundance (%)
		S1		S2		S1		S2		S1		S2		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
Order : Volvoccales														
1	*Pandorina morum* (Mull.) Bory*	5	3	3										9.17
2	*Chlamydomonas reinhardtii* Dangeard*	5	5	4	2									13.33
3	*Chlamydomonas debaryana* Goroschankin*	6	4	2	2	3								14.17
4	*Chlamydomonas intermedia Chodat**	5	2	3										8.33
Order : Chlorococcales														
5	*Chlorococcum infusionum**	7	5	4	6					6	3	2	4	30.83
6	*Chlorococcum humicola* (Nageli)Rabenhorst***	9	3	5	6	4		4	2	7		7		39.17
7	*Chlorococcum minutum* Starr***	7		5	6	5		6	4	7		6		38.33
8	*Chlorococcum macrostigmatum* Starr***	9	6		5	4	4	5	5	5	3			38.33
9	*Myrmecia bisecta* Reisigl*					9	6	6	7					18.33
10	*Dictyochloropsis reticulatum (Tschermak Woess)Tschermak Woess**	9				7	8			7	5	3	5	36.67
11	*Dictyochloropsis splendida* Geitler var. splendida*	8				8	7			6	4	3	7	35.83
Order : Sphaeropleales														

12	*Dictyococcus varians* Gerneck*	4		2	4									8.33
13	*Gleocystis gigas* (Kutzing) Lagerheim*	5								4	3	3	5	16.67
14	*Characium accuminatum* A.Braun ex Kuetzing*	5	4	4										10.83
15	*Pediastrum duplex* Meyen reticulatum**							3	5				6	11.67
16	*Pediastrum tetras***Ehr (Ralfs)								4			3		5.83
17	*Scenedesmus alternans* Reinsch***	9	6		5	6	6	4	8	5	5	3	3	50.00
18	*Scenedesmus arcuatus* Lemmermann***	7	5	4	4	7	4	5	3	7	5		3	45.00
19	*Scenedesmus brasiliensis* Bohlin**	7		4	4	6	4	3	2	6		2		31.67
20	*Scenedesmus quadricauda Var.*Quadrispina (Chodat) G.M .Smith***	9		3	2	7	6	3	3			2	2	30.83
21	*Scenedesmus bijuga* (Turpin) Kutzing***	7	5	2	1	6	3	2	2	5	5			31.67
22	*Coelastrum reticulatum* (Dangeard) Senn.**						4	5	4					10.83
23	*Coelastrum astroidem* De Notaris**							4	3					5.83
24	*Coelastrum microsoprum* Nageli **		5					6	5			5		17.50
25	*Coelastrella terrestres* (Reisigl) Hegewald & Hanagata*	9	7	4	4		5	7						30.00
26	*Coelastrella vacuolata* (Shihira et krauss) Hegewald et Hanagata*	9	8	5	4									21.67
27	*Bracteacoccus minor* (Chodat) Petrova*					6	6	9	8			9		31.67
28	*Selenastrum gracile* Reinsch*					5	4							7.50
29	*Ankisrodesmus densus* Korshikov*			3										2.50
30	*Ankistrodesmus falcatus*(Corda) Ralfs*	2	2											3.33
31	*Monoraphidium griffithii (Berkeley) Komarkova Legnerova**	2	2											3.33
Order :Ulothricales														
32	*Ulothrix moniliformis* Kutzing**					2	3							4.17
Order : Odegoniales														
33	*Oedogonium sp***	2	5	6	4									14.17
34	*Oedogonium sp***	2	5											5.83
Order :Microsporales														

35	*Microspora tumidula* Hazen*	4	6											8.33
Order : Chaetophorales														
36	*Chaetophora attenuata Hazen* **	5	3					4	4					13.33
37	*Chaetophora elegans* (Roth) C.A.Agardh**	4	3					3	3					10.83
Order : Chladophorales														
38	*Cladophora glomerata* (L.) Kutzing**	3	2					5	5	4				15.83
Order : Chlorellales														
39	*Chlorella minutissima* Fott et Novakova*	6		3	2	7	6	4	4	3			1	30.00
40	*Chlorella vulgaris* Beyerinck*								4	8	7	3	3	20.83
41	*Chlorella minuta* (Nageli)Oltmanns*									9	9	8	8	28.33
42	*Keratococcus bicaudatus* (A.Braun ex.Rabenhorst) J.B Petersen*			2	2									3.33
Order : Oocystales														
43	*Oocystis solitaria* Wittrock*		2	1										2.50
44	*Oocystis elliptica* West*		2											1.67
45	*Sideroceles ornata* (Fott) Fott*		1											0.83
Order : Prasioles														
46	*Stichococcus bacillaris* Nageli*					4	5	9	9					22.50
47	*Hormdium fluitans* (Gay) Heering**							3	5					6.67
Order : Klebsormidiales														
48	*Klebsormidium flaccidum* (Kutzing) S.Mattox et Black well**					6	6	7	8					22.50
Order : Zygnemales														
49	*Mesotaenium macrococcum* (Kutzing) Royet Bisset***							9	8			9	7	27.50
50	*Cylindrocystis crassa* De Bary*	2	3	1	3									7.50
51	*Closterium jenneri* Ralfs var.jenneri**							4	6			5	5	16.67
52	*Closterium navicula* (Breb) Lutkemuller**								5			4	4	10.83
53	*Closterium pusillum* Hantzsch**							2	6			1	1	8.33
54	*Closterium incurvum* Brebisson**							3	6	2		2	2	12.50
55	*Closterium kuetzingii* Berb var.kuetzingii**							1	2				1	3.33
56	*Closterium closteroides* (Ralfs) Lousis et Peeters							3	3			2	2	8.33

	var.intermedium Roy et Bisset**													
57	*Pleurotaenium trabecula* (Ehrenb.) Nageli**								1				2	2.50
58	*Euastrum ceylanicum*(W.et GS West) Krieger**								1				1	1.67
59	*Euastrum spinulosum* Nordstedt**	2	1	2	5									8.33
60	*Micrasterias foliacea* Bailey ex Ralfs**	2	3	2	1									6.67
61	*Cosmarium blyttii* Wille**							2	3			1	1	5.83
62	*Cosmarium quadratulum* (Breb) Arch.**							2	2			1	1	5.00
63	*Cosmarium auriculatum* Reinsch**							3	4			2	2	9.17
64	*Cosmarium quadrum*.Lund**							3	3			1	2	7.50
65	*Cosmarium speciosum* Nordst.**							0	2			1	1	3.33
66	*Cosmarium awadhense* (Prasad and Mehrotra)**											2	1	2.50
67	*Cosmarium granatum* Breb ex Ralfs**							4	4					6.67
68	*Cosmarium angulosum* Berb**							1	2			1	1	4.17
69	*Staurastrum gracile* Ralfs var.coronulatum Boldt forma**								1	1	1		1	3.33
70	*Staurastrum apiculatum* Brebisson**								1			1	1	2.50
71	*Sphaerozosma vertebratum* Breb ex Ralfs **	3	4	3	3									10.83
72	*Actinotaenium turgidum* (Brebisson)Teiling**								1			2	1	3.33
73	*Mougetia scalaris* Hassall**				5			4	5					11.67
74	*Zygnema pectinatum* (Vaucher) Agardh**							6	6		2	5	5	20.00
75	*Spirogyra fluviatilis* Hilse**				7			9	9		4	5	4	31.67
76	*Spirogyra decimina* (Muell) Kuetz **				9			8	7		3	6	3	30.00
77	*Spirogyra longata* (Vaucher)Kutzing**							9	6		3	5	2	20.83
Order : Euglenales														
78	*Euglena gracilis* Klebs**	7			9		3	4	8		4	6	7	40.00
79	*Euglena tripteris* (Dujardin) Klebs**	7			6		5	7	7		4	9	6	42.50
80	*Trachelomonas hispida* (Perty)Stein var.hispida**	5			5		3	5	8		4	7	7	36.67
81	*Trachelomonas superba* Svirenko emend.Deflandre**				4		1	2	5		1	1	5	15.83

82	*Trachelomonas rugulosa Stein***	4			6		2		4		3	7	5	25.83
83	*Trachelomonas armata Lemmermann***	4			5	2	2		3			1	4	17.50
84	*Trachelomonas dubia* (Svirenko) Deflandre**							2	4	1	2	5	4	15.00
85	*Phacus longicauda* (Ehrenberg) Dujardin**	3		3	4		2	3	4			5	5	24.17
86	*Phacus curvicauda* Swirenko.**	5		3	3		6	7	7					25.83
87	*Phacus acuminatus* Strokes var. variabilis (Lemmermann)**			8	9		4	4				8	9	35.00
	Total number of species	**40**	**29**	**27**	**33**	**19**	**25**	**48**	**56**	**18**	**21**	**42**	**43**	

***Species seen only in culture **Species seen only in soil sample ***Species seen both in soil and culture**

Population characteristics of algae are given in Table -2, Relative abundance is expressed in Figure -2, Species richness and diversity index of all groups in Table-3 and soil chemical characteristics in Table-4. In all tables R1 represents the Upper *Kuttanadu*, R2 represents the Lower *Kuttanadu* and R3 represents the *Kayal* Lands; S1 represents the Pre-monsoon (*Puncha*) crop and S2 represents the Monsoon (*Virippu*) crop; G1 represent the seedling growth stage and G2 represents the mature growth stage. **Plates 1 - 7** shows photographs of all the 87 species found out.

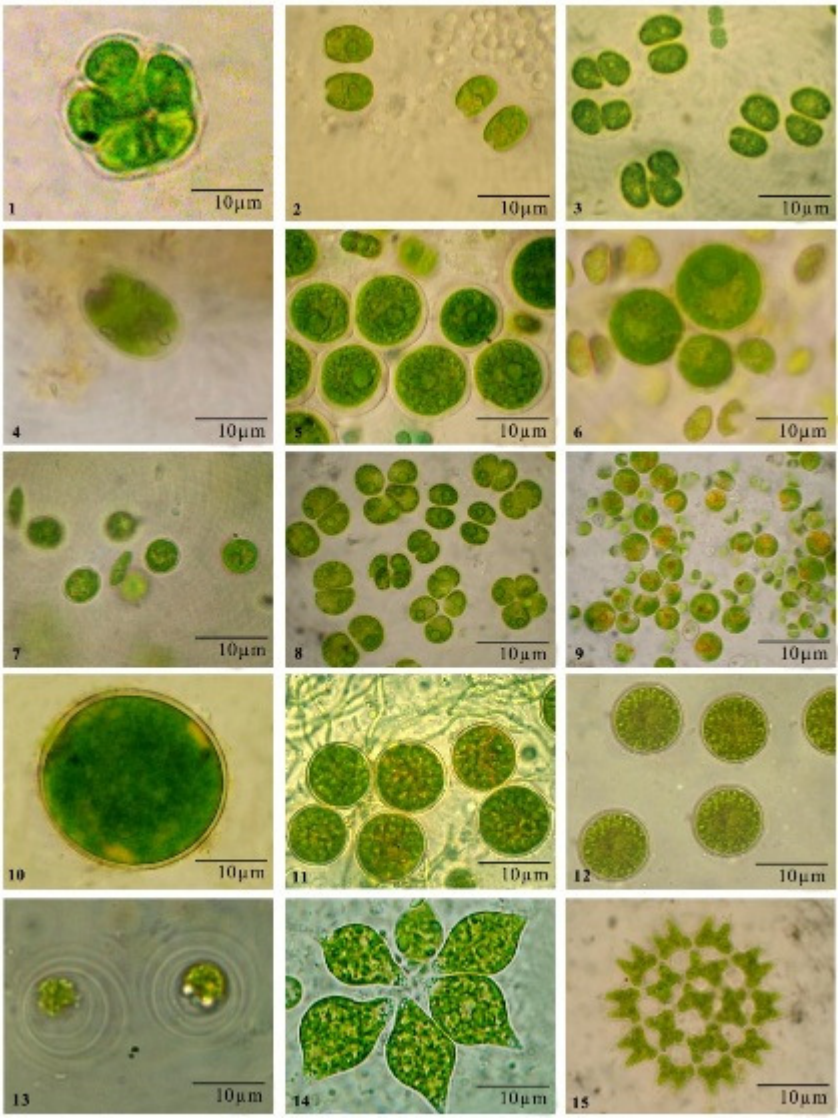

Plate 1 (Figs.1-15): 1. *Pandorina morum* (Mull.) Bory, 2. *Chlamydomonas reinhardtii* Dangeard, 3. *Chlamydomonas debaryana*, 4. *Chlamydomonas intermedia* Chodat, 5. *Chlorococcum infusionum* (Schrant) Meneghini, 6. *Chlorococcum humicola* (Nageli) Rabenhorst, 7. *Chlorococcum minutum* Starr, 8. *Chlorococcum macrostigmatum* Starr, 9. *Myrmecia bisecta* Reisigl, 10. *Dictyochloropsis reticulatum* (Tschermak-Woess) Tschermak Woess, 11. *Dictyochloropsis splendid* Geitlervar. splendida, 12. *Dictyococcus varians* Gerneck 13. *Gleocystis gigas* (Kutzing) Lagerheim, 14. *Characium accuminatum* A. Braunex Kuetzing, 15. *Pediastrum duplex* Meyen.

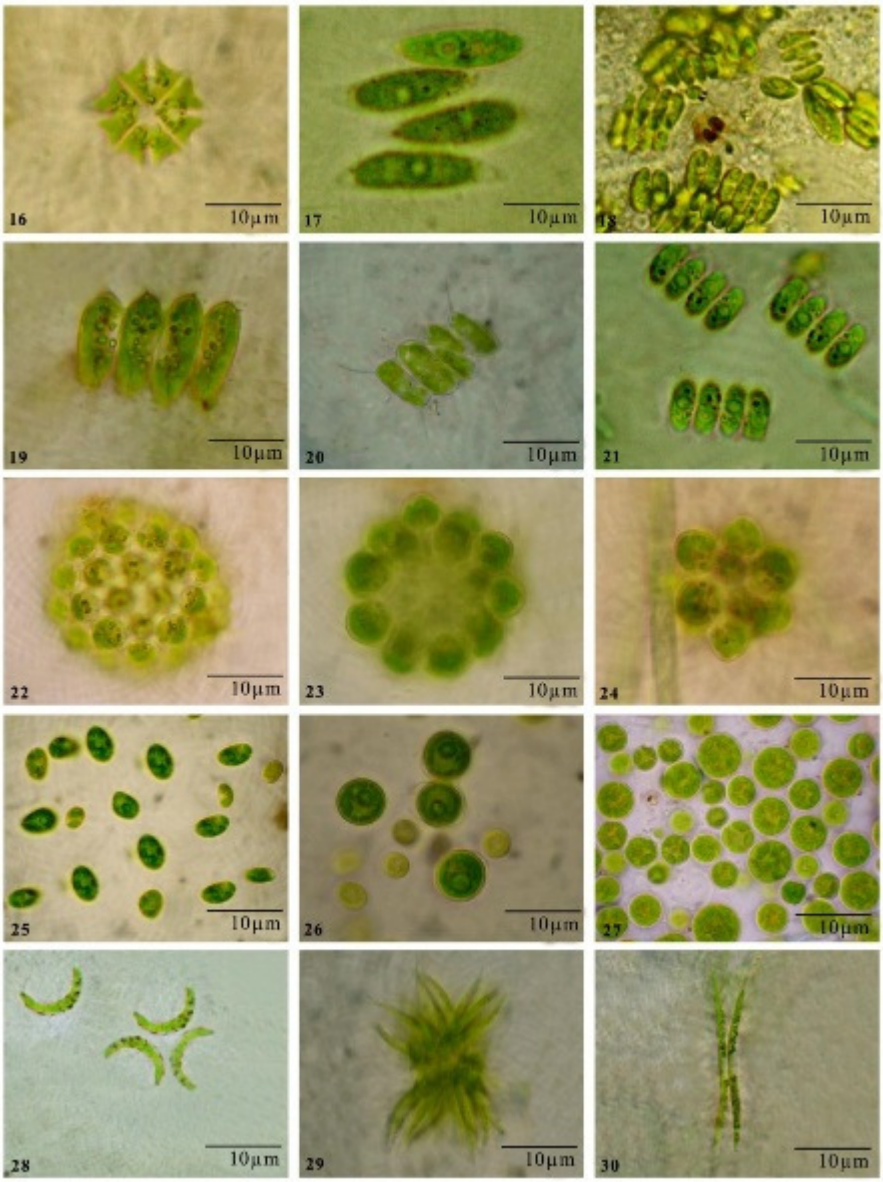

Plate 2 (Figs. 16–30): 16. *Pediastrum tetras* (Ehr.) Ralfs, 17. *Scenedesmus alternans* Reinsch, 18. *Scenedesmus arcuatus* Lemmermann, 19. *Scenedesmus brasiliensis Bohlin*. 20. *Scenedesmus quadricauda* var.quadrispina (Chodat) G.M. Smith, 21. *Scenedesmus bijuga* (Turpin) Kutzing,, 22. *Coelastrum reticulatum* (Dangeard) Senn, 23. *Coelastrum astroidem* DeNotaris 24. *Coelastrum microsoprum* Nageli, 25. *Coelastrella terrestris* (Reisigl) Hegewald & Hanagata, 26. *Coelastrella vacuolata* (Shihira Krauss) Hegewald & Hangata, 27. *Bracteacoccus minor* (Chodat) Petrova, 28. *Selenastrum gracile* Reinsch, 29. *Ankisrodesmus densus* Korshikov, 30. *Ankistrodesmus falcatus* (Corda) Ralfs,

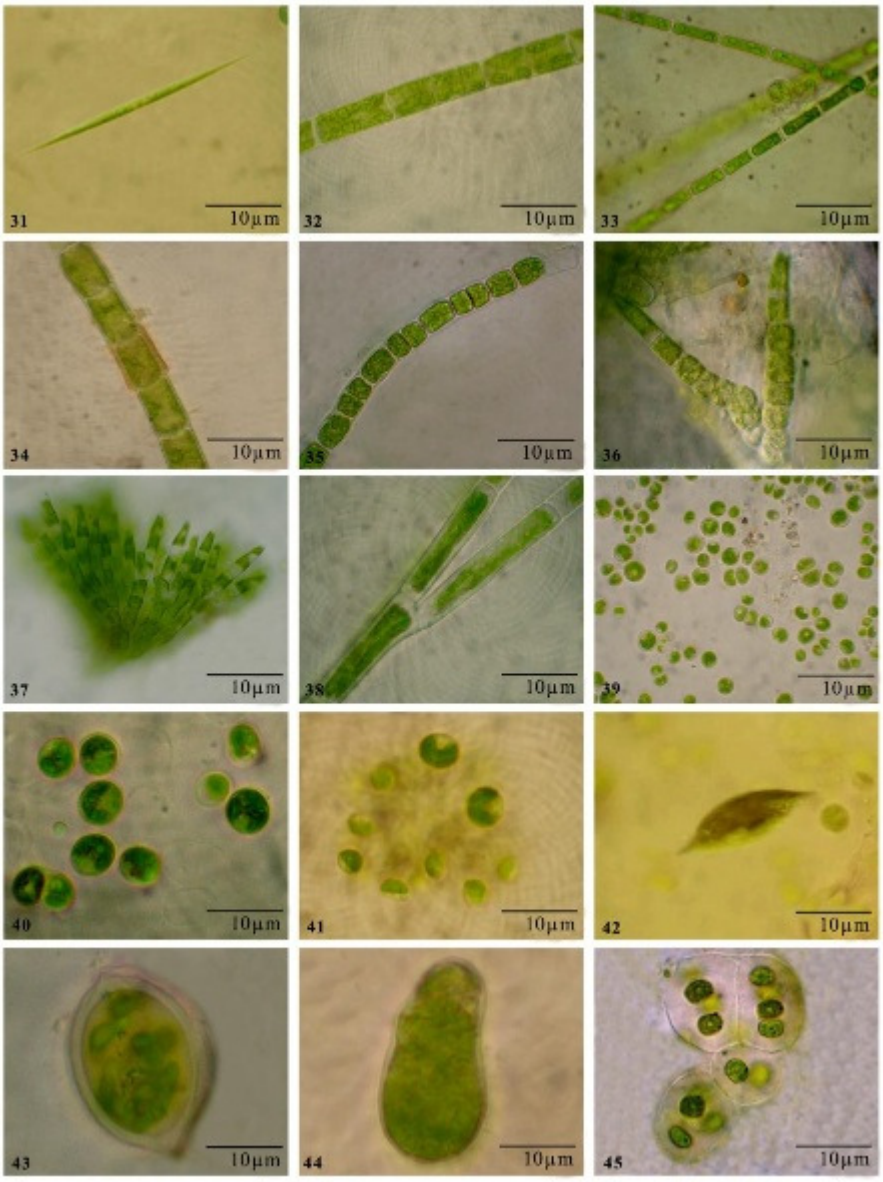

Plate 3 (Figs. 31-45): 31. *Monoraphidium griffithii* (Berkeley) Komarkova-Legnerova, 32. *Ulothrix moniliformis* Kutzing, 33. *Oedogonium sp*, 34 .*Oedogonium sp*, 35. Microspora tumidula Hazen, 36. *Chaetophora attenuata* Hazen, 37. *Chaetophora elegans* (Roth) C. A. Agardh, 38. *Cladophora glomerata* (L.) Kutzing, 39. *Chlorella minutissima* Fottet Novakova 40. *Chlorella vulgaris* Beyerinck, 41.*Chlorella minuta* (Nageli) Oltmanns, 42. *Keratococcus bicaudatus* (A.Braunex. Rabenhorst) J.B Petersen, 43. *Oocystis crassa*, 44. *Oocystis elliptica* West, 45. *Sideroceles ornata* (Fott) Fott

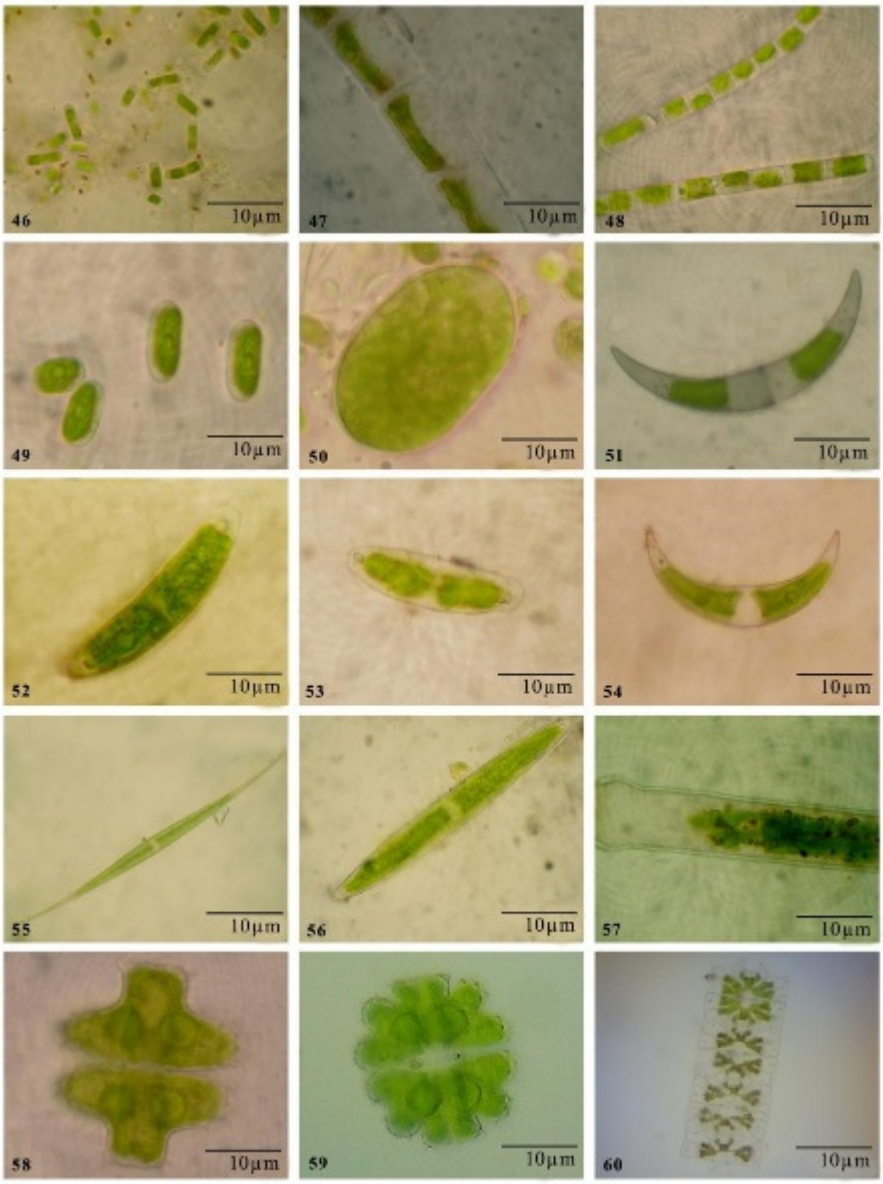

Plate 4 (Figs. 46-60): 46. *Stichococcus bacillaris* Nageli, 47. *Hormidium fluitans*, 48. *Klebsormidium flaccidum* (Kutzing) S.Mattoxet Blackwell, 49. *Mesotaenium macrococcum* (Kutzing) Royet Bisset, 50. *Cylindrocystis* crassa De Bary, 51. *Closterium jenneri* Ralfs var. jenneri, 52. *Closterium navicula* (Brebisson) Lutkemuller, 53. *Closterium pusillum* Hantzsch, 54. *Closterium incurvum* Brebisson, 55. *Closterium kuetzingii* Berbisson var. kuetzingii, 56. *Closterium closteroides* (Ralfs) Lousiset Peeters var.intermedium Royet Bisset, 57. *Pleurotaenium trabecula* (Ehrenb.) Nageli, 58. *Euastrum ceylanicum* (West GS West) Krieger, 59. *Euastrum spinulosum* Nordstedt *60. Micrasterias foliacea* Bailey ex Ralfs

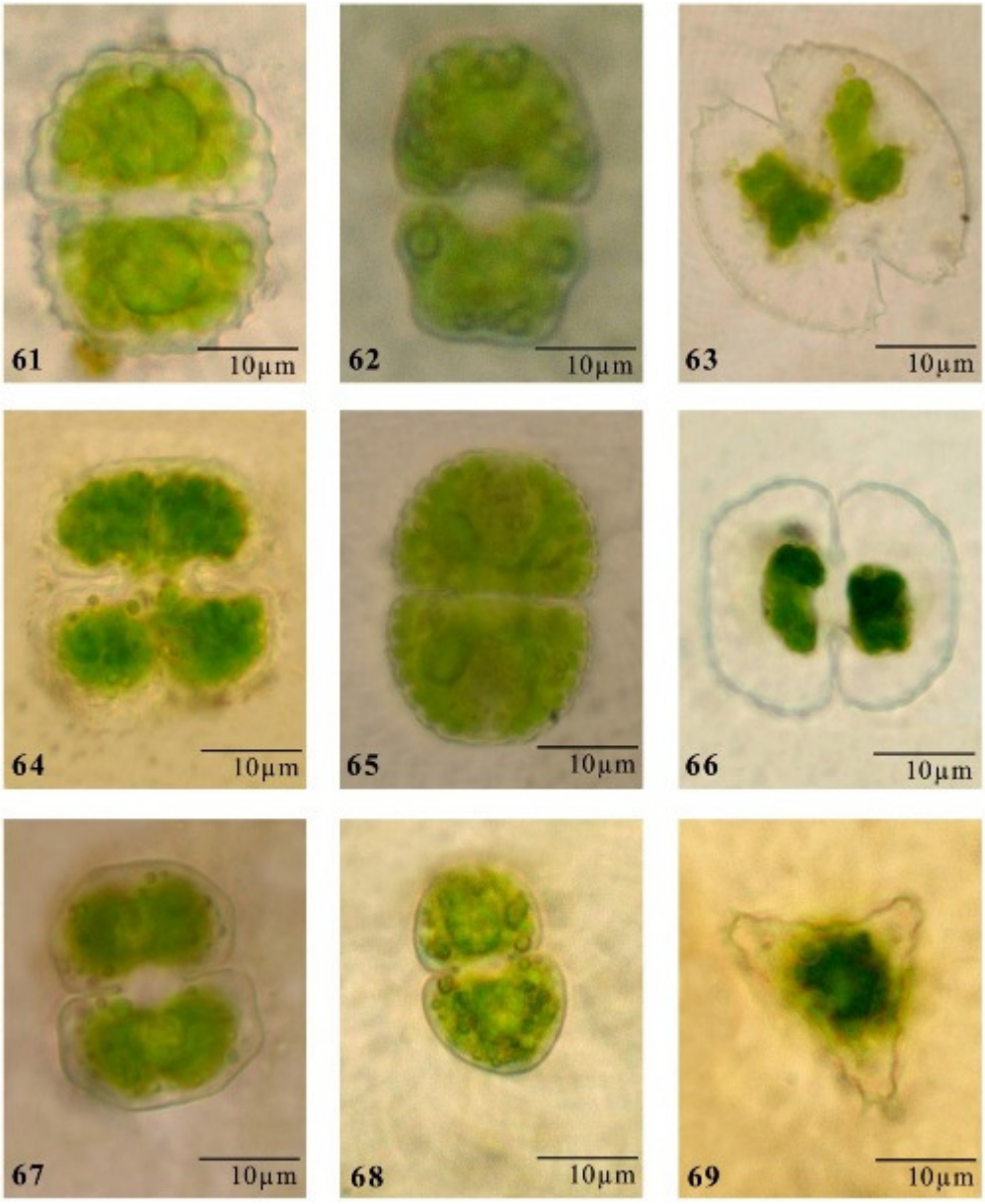

Plate 5 (Figs. 61-69): *61. Cosmarium blyttii* Wille, 62. *Cosmarium quadratulum* (Breb) Arch. 63. *Cosmarium auriculatum* Reinsch, 64. *Cosmarium quadrum*.Lund, 65. *Cosmarium speciosum* Nordst, 66. *Cosmarium awadhense* Prasadand Mehrotra, 67. *Cosmarium granatum Brebex Ralfs*, 68. Cosmarium angulosumBreb 69. *Staurastrum gracile* Ralfs

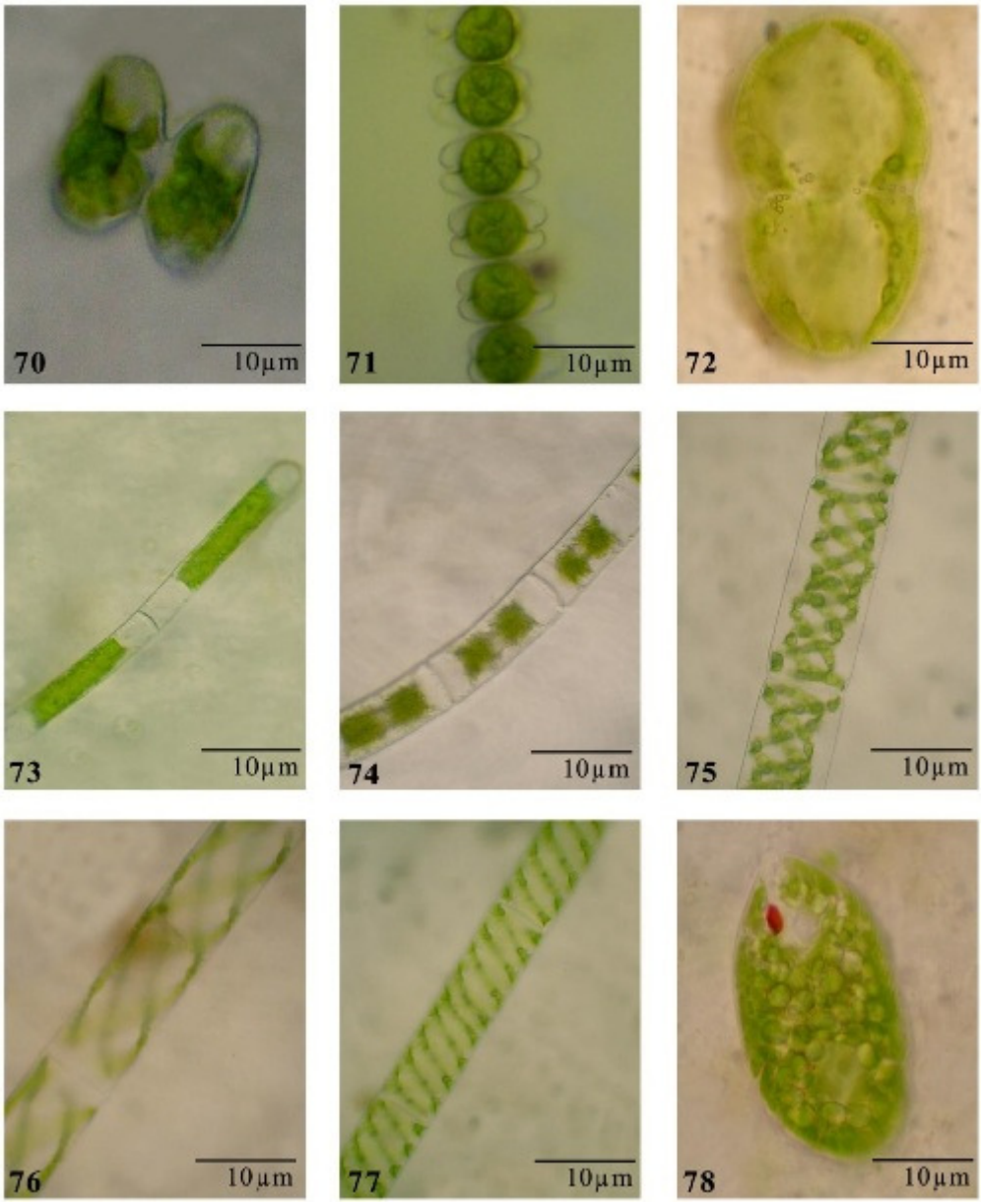

Plate 6 (Figs. 71-78): 70. *Staurastrum apiculatum*, 71. Sphaerozosma vertebratum Brebisson ex Ralfs 72. *Actinotaenium turgidum* (Brebisson) Teiling, 73. *Mougetia scalaris* Hassall, 74. *Zygnema* pectinatum 75. *Spirogyra dubia*, 76. *Spirogyra sp*, 77. *Spirogyra laxissima*, 78. *Euglena gracilis* Klebs

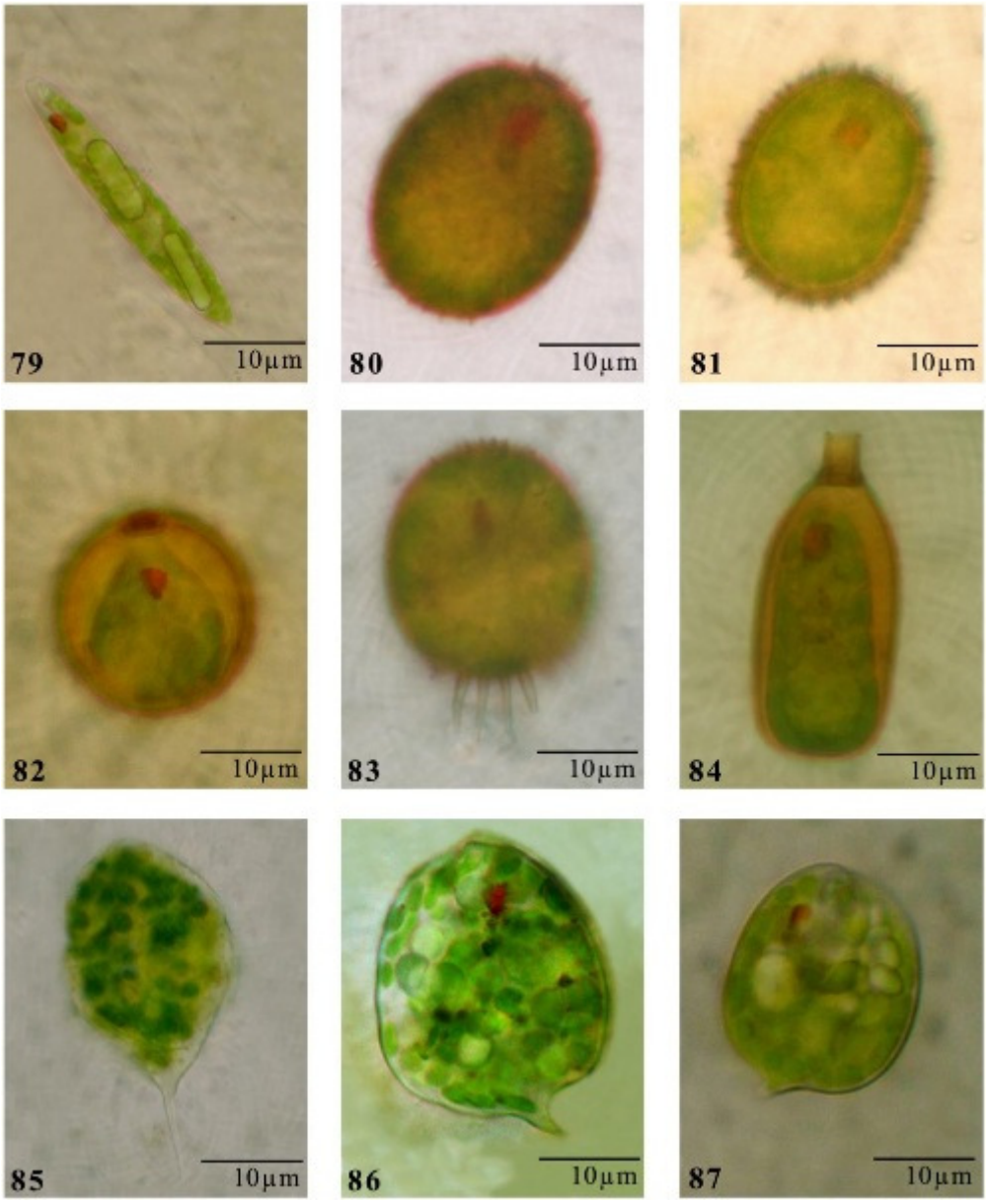

Plate 7 (Figs. 79-87): 79. *Euglena tripteris* (Dujardin) Klebs 80. *Trachelomonas hispida* (Perty) Stein. 81. *Trachelomonas superba* Svirenkoemend. Deflandre, 82. *Trachelomonas rugulosa* Stein, 83. *Trachelomonas armata* Lemmermann, 84. *Trachelomonas dubia* (Svirenko) Deflandre, 85. *Phacus longicauda* (Ehrenberg) Dujardin, 86. *Phacus curvicauda* Swirenko, 87. *Phacus acuminatus* Strokes var. variabilis

Number of species and total isolates

The highest number of total isolates was observed to be 251 in Lower *Kuttanadu,* during *Virippu* season at panicle stage and the lowest number of total isolates (80) was observed from *Kayal* lands during *Puncha* at panicle stage. The highest number of species (56) was observed in the Lower *Kuttanadu* during *Virippu* season at panicle stage and the lowest

number of species was observed (18) in the *Kayal* land during *Puncha* season at the seedling stage (Table: 3).

Table: 3 Species-richness, diversity-index and species-evenness of soil green–algae in different region, seasons and vegetations

Region	Season	Growth Stage	No .of Species	Total Isolates	Sps rich	Div.Ind	Sp. evn
U.K	S1	G1	40	215	0.962	2.54	0.689
		G2	29	112	0.697	2.31	0.686
	S2	G1	27	91	0.649	2.26	0.685
		G2	33	147	0.793	2.40	0.687
L.K	S1	G1	19	104	0.457	2.00	0.680
		G2	25	109	0.601	2.20	0.684
	S2	G1	48	214	1.154	2.67	0.691
		G2	**56**	**251**	**1.346**	**2.79**	**0.692**
K.L	S1	G1	**18**	93	**0.433**	**1.96**	**0.679**
		G2	21	80	0.505	2.08	0.682
	S2	G1	42	164	1.010	2.58	0.690
		G2	43	150	1.034	2.59	0.690

The most abundant species observed in Upper *Kuttanadu* was *Coelastrella vacuolata*; the most dominant of the Lower *Kuttanadu* was *Bractaecoccus minor* and that in the Kayal lands was *Chlorella minuta.* Seasonal analyses show that the most abundant species of *Puncha* season of Upper *Kuttanadu* was *Coelastrella vacuolata,* whereas in the Lower *Kuttanadu* there were three species such as *Myrmecia bisecta*, *Dictyochloropsis reticulatum* and *Dictyochloropsis splendida,* and in the *Kayal* Lands the same was *Chlorella minuta.* During the *Virippu* season the most abundant species of the Upper *Kuttanadu* and *Kayal* land was *Phacus acuminatus* but that in the Lower *Kuttanadu* was *Stichococcus bacillaris*.

Members of Volvocales except *Chlamydomonas debaryana, Dicyococcus varians, Coelastrella vacuolata, Ankistrodesmus sps, Monoraphidium griffithii, Oedogonium sps, Microspora tumidula, Cylindrocystis crassa, Keratococcus bicaudatus, Oocystis sps, Sideroceles ornata, Euastrum spinulosum, Sphaerozosma vertebratum* and *Micrasterias foliacea* were found in Upper *Kuttanadu* soils only. Species such as *Myrmecia bisecta*, *Coelastrum reticulatum, Coelastrum astroiedum, Selenastrum gracile, Ulothrix moniliformis, Stichococcus bacillaris, Hormidium fluitans, Klebsormidium flaccidum* and Cosmarium

granatum were observed in Lower *Kuttanadu* soils only. The species *Chlorella minuta* was observed in *Kayal* land soils only.

Ecological Characteristics of Green algal community in Paddy Soils of *Kuttanadu*

The ecological characteristics included in the present study were relative abundance, species richness, species evenness and diversity index.

The relative abundance (Table 2) of all the 87 green algal species was calculated from 120 soil samples collected from three different regions of *Kuttanadu*. *Scenedesmus alternans* showed the highest relative abundance (50%) followed by *Scenedesmus arcuatus* (45%), *Euglena tripteris* (42%) and Euglena gracilis (40%). The least abundant algae was *Sideroceles ornata* (0.83%) followed by *Oocystis elliptica* and *Euastrum zeylanicum,* both with relative abundance 1.67%.

The species richness showed variation from 0.433 - 1.346 in different regions of *Kuttanadu* during the two crop seasons and crop stages. The diversity index varied from 1.96 - 2.79 and species evenness showed very slight variation from 0.679 - 0.692. All these three parameters were found maximum in Lower *Kuttanad*u, during *Virippu* season at panicle stage. Minimum species richness, diversity index and species evenness were noticed in *Kayal* lands during *Puncha* cultivation at seedling stage (Table-3).

Physico - chemical characteristics of the soil such as pH, total organic carbon (C), total/ Kjeldal nitrogen (N), plant available phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) studied in relation to crop seasons and different stages of paddy growth in the three different regions of *Kuttanadu* are given in Table -4.

Table: 4 Average soil chemical characteristics of wetland paddy fields of *Kuttanadu*
(Ray et al 2014)

No	Location	Crop season	Growth stage	Average pH	Average TN (%)	Average OC (%)	Average available nutrients (kg/ha)			
							P	K	Ca	Mg
1	Upper Kuttanad	Puncha	seedling	3.94	0.429	3. 07	10.86	998.6	3858.8	788.8
2	Upper Kuttanad	Puncha	panicle	3.88	0.392	4.06	18.26	656.9	2378.6	512.2
3	Upper Kuttanad	Virippu	seedling	3.4	0.289	0.942	129	298.7	441.4	177.7
4	Upper Kuttanad	Virippu	panicle	3.65	0.459	2.63	110	496.5	758.2	205. 5
5	Lower kuttanad	Puncha	seedling	4.00	0.413	3.97	7.14	855	1842.4	785.8

6	Lower Kuttanad	Puncha	panicle	4.29	0.374	3.54	25.34	389.2	2841.7	840.2
7	Lower Kuttanad	Virippu	seedling	3.74	0.37	1.68	109	316.7	1078	321.9
8	Lower Kuttanad	Virippu	panicle	3.7	0.52	2.16	95	408.9	1437.4	377.4
9	Kayal lands	Puncha	seedling	4.03	0.39	3.28	9.6	391.2	1249.6	748.5
10	Kayal lands	Puncha	panicle	4.61	0.435	3.7	9.46	396	2331.8	992.1
11	Kayal lands	Virippu	seedling	4.05	0.4	2.49	129	440.9	1466.6	407.3
12	Kayal lands	Virippu	panicle	4.23	0.431	2.68	58	408.3	1618.7	399.9

Environmental Correlations

The green algal species richness and diversity index was correlated to region, seasons and growth stage and soil parameters such as pH, N, P, K, Ca and Mg of different regions of *Kuttanadu* in relation to crop stages and growth stages using Pearson's correlation coefficient. It was observed that crop seasons were positively correlated with species richness ($P < 0.01$) and number of species ($P<0.01$). A significant positive correlation was existed with species richness to total nitrogen ($P < 0.004$) and phosphorus ($P<0.001$). Also a significant negative correlation was observed between species richness to organic carbon ($P<0.002$) and magnesium ($P<0.001$). It was found that green algal diversity index was positively correlated with total nitrogen ($P<0.035$) and phosphorus ($P<0.001$) and negatively correlated to organic carbon ($P<0.002$) and magnesium ($P<0.001$).

It was found that the number of species was positively correlated to total nitrogen ($P<0.05$) and phosphorus ($P<0.01$). The number of species showed significant negative correlation with pH ($P<0.05$), organic carbon ($P<0.01$) and magnesium ($P<0.01$).

DISCUSSION

It is well known that seasonal variations affect algal growth (Sharma et al 2006) and specific terrestrial habitat conditions such as weather or water quality parameters have influences on the diversity of algae of wet soils (Kumar and Sahu 2012). Species richness and diversity index are good measures of algal diversity whereas biomass production and population density are important criteria to assess growth of soil algae (Kabirov and Gaisina 2009). Moreover, vegetation is also known to have positive influence on algal population of surface soils (Broady 1979). Therefore, the current exploration of green algal diversity in relation to

all the above mentioned environmental parameters as was carried out in this unique tropical wetland may be considered as a model holistic approach to the assessment of algal biodiversity of wet soils in general.

Variations in the quantity and quality of diverse species of green algae in relation to the specific environmental conditions are evident in the results of the current exploration of green algae of *Kuttanadu.* Highest values in terms of the number of species (56), total isolates (251), species richness, diversity-index and species evenness are observed in the Lower *Kuttanadu*, during *virippu* season, at panicle stage of the crop. Species richness of green algae over the three different soil regions of *Kuttanadu* Wetlands varied from 0.433-1.346 during the two crop seasons and crop growth stages. Diversity index of algae varied from 1.96 - 2.79 and species evenness from 0.679-0.692. Lowest number of total isolates (80) is found in *Kayal* lands at *Puncha* season in the panicle stage of the crop; the same soil region has also the lowest number of species (18), species richness, diversity-index and species evenness during the same season, but at the seedling stage (Table-3).

Soil algae of terrestrial habitats in general, are correlated to seasonal variations (Quesada et al 1995). Seasonal influence and specific soil characteristics were found to be the important factor governing algal diversity in *Kuttanadu* as well. In all the three zones of *Kuttanadu* all the soil algal parameters were the maximum during the monsoon season. This is in agreement with the observation of previous authors of wetland algal communities (Broady et al. 1979; Baruah et al. 2013; Deb et al. 2013) that the amount and duration of moisture content is the primary factor determining the abundance of algae in soils (Johansen and Rushforth 1985). Green algae in *Kuttanadu* paddy fields were also found positively correlated to monsoon. Similarly, a negative correlation of algal characteristics to temperature is also observed in this investigation as well. Unlike other wetlands, *Kuttanadu* is a land under mean sea level, always flooded with water. Therefore, it is evident that the change in water levels during rainy seasons is not the whole reason for variations in algal communities in relation to seasons; but the complex overall changes in soils and climate in relation to seasons seems the major cause of such variations.

Soil texture and organic carbon content are highly significant factors affecting the abundance and species diversity of soil algae (El-Gamal et al 2008). In the present study, highest number of green algal species was reported from the Lower *Kuttanadu* soils, which in terms of organic carbon content (1.6 to 3.9 %) is different from the other two soil regions.

Soils of this region are clay loams characterized by high acidity and a fairly high amount of decomposing organic matter and nitrogen (0.37 to 0.52 %). High levels of nitrogen in the soil favour the dominance of Chlorophyta (Ohtani et al. 2000).

Among the soil properties, pH is considered to be the most important factor determining the composition of soil algal flora (Roger and Reynaud 1982). The pH of Lower *Kuttanadu* soils varied from 3.7 to 4.2. Green algae prefer acidic soils than alkaline and neutral soils (Schlichting 1973). However, a negative correlation of pH to total number of species is observed in *Kuttanadu*, which is in agreement with certain previous findings (Novakovskaya and Patova 2008) but contradictory to certain other observations (Lukesova et al. 2001). In addition to pH and other the soil characteristics, fertilizers and lime applications can also have influence on the biodiversity of green algae in paddy fields (Lukesova 2001; Lin et al. 2013).

Light availability has positive influence of algal community on wetlands (Roger and Reynaud 1982). In the present study, diversity of green algae was higher in panicle stage than in seedling stage, except in the Upper *Kuttanadu* during the first crop season, *Puncha*. In the Lower *Kuttanadu*, number of species, total isolates, species richness, diversity index and species evenness were found the highest at the panicle stage during the second cultivation season, *Virippu*. Here a gradual increase in algal diversity along with the increase in rice canopy was observed. This is in agreement with the previous observation that during panicle initiation, algal biomass reached its highest values and green algae became dominant in certain wet soils (Roger and Reynaud 1982). Similarly a decrease in light intensity followed by depletion of the nutrients was found positively correlated to green algal community in rice fields (Choudhary 2011). However, a decrease in light availability from increased vegetation cover and litter accumulation is expected to a decrease in green algal diversity (Lukesova et al. 2001) in terrestrial soils. In the present investigations, species richness, diversity index and number of species of green algae were all found positively correlated to total nitrogen and phosphorus, but the same were found negatively correlated to organic carbon and magnesium. These observations are also in agreement with certain previous report (Vijayakumar et al. 2007) that nitrates and phosphates are important factors affecting algal growth. Understanding of algae in wet soils is important to sustainable management of soil fertility. It is true that the contributions of soil green algae to organic matter of soils is

negligible (Kabirov and Gaisina 2009), but the overall ecological benefits of algae to soils are highly complex, and important to be revealed.

Conclusions

In nut shell, the present investigations have revealed that *Kuttanadu* wetland paddy soils are very rich in green algal diversity, dominated mostly by species from the order Zygnemales (33%). Certain specific species unique to the soil regions, seasons and growth stages in *Kuttanadu* are also revealed. Species richness and number of species were found positively correlated to crop seasons. Highest number of isolates (251) and the highest number of species (56) were observed in the Lower *Kuttanadu* soil region, during the *Virippu* season, at panicle growth stage of the crop. Algal biodiversity appeared to be the maximum during monsoon season throughout the region. Species richness was highest in Lower *Kuttanadu* soils and lowest in *Kayal* lands. *Scenedesmus alternans* was the most abundant green algae in *Kuttanadu*. The most abundant species observed in Upper *Kuttanadu* was *Coelastrella vacuolata*; in the Lower *Kuttanadu* soils it was *Bractaecoccus minor* and in the *Kayal* lands the same was *Chlorella minuta.* Beneficial roles of green algae to growing crops are evident from its correlation to crop growth stages in the soils. Therefore, it is highly necessary to explore the specific role of algal associations to crops, which is important to soil fertility management towards development of sustainable agriculture. Measures to conserve algal genetic resources of all the local terrestrial habitats are also very important in this regard. The present study of green algae in relation to soil parameters in the *Kuttanadu* Wetlands emphasizes the need of such systematic analyses to understand the ecology of soil algae in diverse terrestrial habitats in association with different crops.

References

[1] Bahaar S.W.N. and Bhat G.A. 2011. Aquatic biodiversity in the paddy fields of Kashmir valley, India. Asian Journal of Agricultural Research 5(5): 269-276

[2] Baruah P.P., Baruah R. and Thakuria J. 2013. Chlorophyceaen diversity of Deepor Beel Wildlife sanctuary. Phycos 43(2): 33-42

[3] Bray R.H. and Kurtz L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59: 39-45

[4] Broady P.A. 1979. Quantitative studies on the terrestrial algae of Signy Island, South Orkney Islands. British Antartic Survey Bulletin 47: 31-41

[5] Choudhary K.K. 2011. Occurence of nitrogen fixing cyanobacteria during different stages of paddy cultivation. Bangladesh Journal of Plant Taxonomy 18 (1):73-76

[6] Comerton M. and Houghton J. A. 1978. The effects of fertilizers on the algal flora of peat. Proceedings of the Royal Irish Academy 8: 233-245

[7] Deb S., Sarma B., Rout J. and Sengupta M. 2013. Algal diversity in soil crusts of Assam University, Silchar Campus (North East India). Phykos 43(1): 56-67

[8] Demirbas A. and Demirbas M. F. 2011. Importance of algae oil as a source of biodiesel. Energy Conservation and Management 52: 163-170

[9] El-Gamal A.D., Nady A., Ghanem E., Eisha Y.E., l- Ayouty and Shehatha E. F. 2008. Studies on soil algal flora in Kafrel- sheikh Governnorate of Egypt. Egyptian Journal of Phycology 9: 1-23

[10] Eric Freyfogle 2007. Wetlands of Kerala. State of the Environment Report 1: 85-193.

[11] Gayatri R. and Raveendran K. 2009. Exploration of untapped potentiality of costal paddy fields of Kerala (India) - A Case Study. Middle- East Journal of Scientific Research 4(1): 44-47

[12] Graham, L.E. and Wilcox L.W. 2000. Algae of Upper Saddle River, New Jersey. Prentice Hall.

[13] Guiry M.D. and Guiry G.M. 2012. Worldwide electronic publication, National University of Ireland, Galway: http://www.algaebase.org

[14] Guru S.D., Sonia Kumari and Kalpana Verma 2013. Bio-survey of algal population (Chlorophyceae) with limnological variables in some tropical fresh water shallow lakes. Phycos 43 (1): 68-76.

[15] Inubushi K. and Acquaye S. 2004. Role of microbial biomass in biochemical processes in paddy soil environments. Soil Science and Plant Nutrition 50(6): 793-805.

[16] Iyangar M.O.P. and Desikachary T.V. 1981. Volvocales. ICAR, New Delhi

[17] Jackson M. L. 1973. Soil Chemical analysis. Prentice Hall of India, New Delhi, India

[18] Johansen J.R. and Rushforth S.R. 1985. Cryptogamic soil crusts: Seasonal variation in Algal populations in the Tintic mountains, Juab Country, Utah. Great Basin Naturalist 45: 14-21.

[19] Kabirov R.R. and Gaisina L.A. 2009. Parameters of the productivity of soil algae in terrestrial ecosystem. Eurasian Soil Science 42: 1374-1379.

[20] Kogel- Knabner I., Amelung W., Zhihong C., Fiedler S., Peter F., Jahn R., Karsten K., Kolbl A. and Schloter M. 2010. Biochemistry of paddy soils. Geoderma 157: 1- 4

[21] Kumar A. and Sahu R. 2012. Diversity of Algae (Chlorophyceae) in paddy fields of Lalgutwa area, Ranchi, Jharkhand. Journal of Applied Pharmaceutical Science 2 (11): 092-095.

[22] Lartey R. T. 2006. Dynamics of soil flora and fauna in biological control of soil inhabiting plant pathogens. Plant Pathology Journal 5: 125-142.

[23] Lin C., Chou T. and Wu J. 2013. Biodiversity of soil algae in the farmlands of mid-Taiwan. Biological Studies 54: 41.

[24] Lukesova A. 2001. Soil Algae in Brown coal and Lignite Post mining areas in Central Europe (Czech Republic and Germany). Restoration Ecology 9: 341-350.

[25] Mansour H.A. and Shaaban A. 2010. Algae of soil surface layer of Wadi Al-Hitan protective area (World Heritage site), El-Fayum depression, Egypt. Journal of American Science 6: 243-255.

[26] Mathew E.K., Panda R.K. and Madhusudan N. 2001. Influence of subsurface drainage on crop production and soil quality in low-lying acid sulphate soil. Agricultural Water Management 47: 191-209.

[27] Metting B. 1981. The Systematics and Ecology of Soil Algae. The Botanical Review l47 (2): 195-312.

[28] Nair U. G. S. 2013. Kuttanadu, Our Heritage. Kerala Calling. 16-21

[29] Novakovskaya I.V. and Patova E.N. 2008. Green algae in spruce forests in the north-east of European Russia. Biologia 63(6): 836-812.

[30] Ohtani S., Kousuke S., Yamamoto H., AridomiY., Ritsuko I. and Fukuoka Y. 2000. Distribution of soil algae at the monitoring sites in the vicinity of Syowa Station between austral summers of 1992/1993 and 1997/1998. Polar Bioscience 13: 113-132.

[31] Patova E.N. and Dorokhova M.F. 2008. Green algae in tundra soils affected by coal mine pollutions. Biologia 63 (6): 831-835.

[32] Pena-Castro J.M.F., Martinez-Jeronimo, Esparza-Garcina F. and.Canizares-Villanueva R.O. 2004. Heavy metals removed by the microalgae Scenedesmus incrassatulus in continuous cultures. Bioresearches Technology 94: 219-222.

[33] Pham M.N., Tan H.T.W., Mitrovic S. and Yeo H.T.T. 2011. A Checklist of the algae of Singapore 2nd Edn. Raffles Museum of Biodiversity Research, National University of Singapore.

[34] Philipose M.T. 1967. Chlorococcales. Indian Council of Agricultural Research, NewDelhi, India.

[35] Pillai V.K., Ponniah A.G., Vincent D. and David Raj I. 1983. Acidity in Vembanadu Lake causes fish mortality. Marine Fisheries Information Service, Technical and Extension Series, 53: 8-15

[36] Prakongkep N., Suddhiprakarn, A., Kheoruenromne I., Smirk M. and Gilke R.J. 2008. The Geochemistry of Thai paddy soils. Geoderma 144: 310-324.

[37] Prescott G.W.1951. Algae of the Western Great Lakes Area. First Edition.WMC Brown Publishers, Dubuque Lowa, USA.

[38] Quesada A., Sanchez- Maeso E. and Fernandez- Valiente E. 1995. Seasonal variations of chemical properties of rice field soils from Valencia, Spain. Communications in Soil Science and Plant Analysis 26 (1-2): 1-19.

[39] Roger P.A. and Reynaud P.A. 1982. Free living blue green algae in tropical soils. In: Y. Dommergues and H. Diem (eds) Microbiology of tropical soils and plant productivity. Martinus Nijhoff Publisher, Hague, pp 147- 168.

[40] Roger P.A., Zimmerman W.J. and Lumpkin T. 1993. Microbiological management of Wetland rice fields. In: F.B meeting Jr (ed.) Soil microbial ecology: application in agricultural and environmental management, New York.

[41] Sahrawat, K.L. 2008. Soil fertility Advantages of Submerged Rice cropping Systems. Journal of Sustainable agriculture 31(3): 5-23.

[42] Schliching H.E. (1973). Algae in Tobacco beds, Transactions of American Microbiological Society 92(3): 528-531.

[43] Shannon C.E. and Weaver W. 1949. The Mathematical Theory of Communication, University of Illinois Press, Urbana.

[44] Shari P.V. and Chitra K.P. 2005. Kuttanadinte charithravum bhoomisastravum (History and geography of Kuttanadu). In: Joseph M J (ed.) Kuttanadinte Jala Punarjjeevana Prayoga Sadhyathakal (Water Reclaiming in Kuttanadu, Possible Chances), Planet Kerala, Trivandrum (In Malayalam), pp.9-18.

[45] Sharma N.K., Singh S. and Rai A.K. 2006. Diversity and Seasonal variation of viable algal particles in the atmosphere of a sub-tropical city in India. Environmental Research 102: 252-259.

[46] Shayler H.A. and Siver P.A. 2006. Key to fresh water algae: A web based tool to enhance understanding of microscopic biodiversity. Journal of Science Education and Technology 15 (3): 298-303.

[47] Sudhikumar A.V., Mathew M.J., Sunish E. and Sebastian P.A. 2005. Seasonal variation in spider abundance in Kuttanadu rice agroecosystem, Kerala, India. Acta Zoologica Bulgarica 1: 181-190.

[48] Thomas P. M. 2002. Problems and prospects of paddy cultivation in Kuttanadu region - a case study of Ramankari village in Kuttanadu Taluk. A Project of Kerala Research Programme on local level development (KRPLLD), Thiruvananthapuram.

[49] Vijayakumar S., Thajuddin N. and Manoharan C. 2007. Biodiversity of Cyanobacteria in industrial effluents. Acta Botanica Malacitana 32: 27-34.

[50] Walkley A. and Black I.A. 1934. An examination of Degtjareff Method for determining soil organic matter and a proposed modification of the chronic acid titration method. Soil Science 37: 29-37.

[51] Whittaker R.H. 1977. Evolution of species diversity in land community. In: Heeht M.K., Stee W.C.and Wallace B. (eds.) Evolutionary Biology, Plenum, New York.

[52] Zancan, S., R. Trevisan and Paoletti M.G. 2006. Soil algae composition under different agro-ecosystem in North-Eastern Italy. Agriculture Ecosystem and Environment 112: 1-12